

# **ANTI-STICTION TECHNIQUE FOR THIN FILM AND WAFER-BONDED ENCAPSULATED MICROELECTROMECHANICAL SYSTEMS**

This invention relates to electromechanical systems and techniques for fabricating microelectromechanical and/or nanoelectromechanical systems; and more particularly, in 5 one aspect, to fabricating or manufacturing microelectromechanical and nanoelectromechanical systems having mechanical structures that are encapsulated using thin film or wafer bonding encapsulation techniques, and including suitable anti-stiction characteristics.

Microelectromechanical systems ("MEMS"), for example, gyroscopes, resonators 10 and accelerometers, utilize micromachining techniques (i.e., lithographic and other precision fabrication techniques) to reduce mechanical components to a scale that is generally comparable to microelectronics. MEMS typically include a mechanical structure fabricated from or on, for example, a silicon substrate using micromachining techniques.

MEMS often operate through the movement of certain elements or electrodes, 15 relative to fixed or stationary electrodes, of the mechanical structures. This movement tends to result in a change in gap distances between moving electrodes and stationary or fixed electrodes (for example, the gap between opposing electrodes). (See, for example, U.S. Patent 6,240,782, 6,450,029 , 6,500,348, 6,577,040, 6,624,726, and U.S. Patent Applications 2003/0089394, 2003/0160539, and 2003/0173864). For example, the MEMS 20 may be based on the position of a deflectable or moveable electrode of a mechanical structure relative to a stationary electrode.

The mechanical structures are typically sealed in a chamber. The delicate mechanical structure may be sealed in, for example, a hermetically sealed metal container (for example, a TO-8 "can", see, for example, U.S. Patent No. 6,307,815), bonded to a semiconductor or glass-like substrate having a chamber to house, accommodate or cover 5 the mechanical structure (see, for example, U.S. Patent Nos. 6,146,917; 6,352,935; 6,477,901; and 6,507,082), or encapsulated by a thin film using micromachining techniques during, for example, wafer level packaging of the mechanical structures. (See, for example, International Published Patent Applications Nos. WO 01/77008 A1 and WO 01/77009 A1).

In the context of the hermetically sealed metal container, the substrate on, or in 10 which the mechanical structure resides may be disposed in and affixed to the metal container. The hermetically sealed metal container also serves as a primary package as well.

In the context of the semiconductor or glass-like substrate packaging technique, the substrate of the mechanical structure may be bonded to another substrate whereby the 15 bonded substrates form a chamber within which the mechanical structure resides. In this way, the operating environment of the mechanical structure may be controlled and the structure itself protected from, for example, inadvertent contact. The two bonded substrates may or may not be the primary package for the MEMS as well.

Thin film wafer level packaging employs micromachining techniques to encapsulate 20 the mechanical structure in a chamber using, for example, a conventional oxide ( $\text{SiO}_2$ ) deposited or formed using conventional techniques (i.e., oxidation using low temperature techniques (LTO), tetraethoxysilane (TEOS) or the like). (See, for example, WO 01/77008

A1, Figures 2-4). When implementing this technique, the mechanical structure is encapsulated prior to packaging and/or integration with integrated circuitry.

Under certain conditions, for example, during operation, the deflectable or moveable electrode may contact the stationary or fixed electrode and the electrodes may become stuck. This may be the result of, for example, rapid, sudden and/or violent movement of the MEMS. When electrodes of a mechanical structure become stuck, it is generally known as stiction. Stiction is common in MEMS and may be caused by, for example, van der Waals force, cold welding, arcing, molecular or atomic bonding, surface tension of, for example, liquids formed on the contacting parts, and/or electrostatic forces due to surface charge.

10 Stiction typically renders the MEMS inoperative.

There are many different and diverse techniques/approaches to address, minimize, overcome and/or avoid the debilitating affects of stiction. (See, for example, U.S. Patent Nos. 6,621,392, 6,625,047 and 6,625,342 and U.S. Patent Application Nos. 2003/0155643 and 2003/0178635). One approach is to apply a lubricant or passivation layer, for example, 15 perfluorodecanoic acid ("PFDA") on the mechanical structure, including the moveable and fixed electrodes. In this regard, PFDA may be deposited in a monolayer, typically through a vapor deposition, and forms an extremely low energy surface. (See, for example, U.S. Patent Application No. 2003/0161949). This approach is quite common in substrate packaging technique.

20 In wafer level packaging of mechanical structures, however, the thin encapsulation film is often deposited at high temperatures. In addition, additional or further processing, for example, MEMS integration with electronic circuitry often requires use of high temperature processes (for example, during the formation or fabrication of the integrated

circuits). Conventional lubricants or passivation layers are susceptible to destruction when subjected to those temperatures required for fabricating the thin film encapsulation or integrated circuits. Thus, after encapsulation, the mechanical structures are more prone to stiction as a consequence of the post-mechanical structure processing.

5        There is a need for, among other things, a MEMS employing an anti-stiction technique that is compatible with thin film encapsulation and/or wafer bonding techniques and overcomes one, some or all of the shortcomings of the conventional anti-stiction techniques. There is a need for, among other things, a MEMS including mechanical structures that is encapsulated using thin film encapsulation and/or wafer bonding  
10      techniques, that possesses suitable anti-stiction techniques and overcomes the cost, design, operation and/or manufacturing shortcomings of conventional anti-stiction techniques. There is a need for a MEMS having low adhesion energy mechanical structures that are encapsulated using wafer level thin film and/or wafer bonding encapsulation techniques.

15                  **SUMMARY OF THE INVENTION**

There are many inventions described and illustrated herein. In a first principal aspect, the present invention is a method of manufacturing an electromechanical device having a mechanical structure that is disposed in a sealed chamber which is formed, at least in part, by an encapsulation layer. The method comprises forming at least one anti-  
20      stiction channel through the encapsulation layer and introducing an anti-stiction fluid (for example, DDMS, OTS, PFOTCS, PFDA, FOTS, PFPE or FOTS) into the chamber via the

anti-stiction channel wherein the anti-stiction fluid forms a monolayer or self-assembled layer on at least a portion of the mechanical structure. The method further includes depositing an anti-stiction plug (for example, spin-on polymer, SOG or a metal material) over or in the anti-stiction channel to re-seal the chamber.

- 5        The anti-stiction channel may be formed using anisotropic etching (for example, using reactive ion etching). The anti-stiction plug may be deposited using silk screening, shadow mask technology, or dispensed seal-glass, plastic or epoxy.

In one embodiment, the electromechanical device further includes a contact area and the method further includes forming a trench around the contact area, wherein the  
10 contact area is at least partially disposed outside the chamber, and depositing a first insulating material in the trench to electrically isolate the contact area. The method may also include depositing a second insulating layer over at least a portion of the trench and forming an anti-stiction window in the insulating layer before forming the at least one anti-stiction channel through the encapsulation layer. A highly conductive material may be  
15 deposited on the contact area and over the second insulating layer to provide electrical connection to the contact area wherein at least a portion of the anti-stiction plug is comprised of the highly conductive material.

In one embodiment, the method includes depositing a diffusion barrier on the anti-stiction plug. The diffusion barrier may be, for example, comprised of a polysilicon,  
20 germanium, silicon/germanium, silicon dioxide, silicon nitride, BPSG, PSG, SOG or metal bearing material. Indeed, a highly conductive material deposited on the contact area and over the insulating layer and anti-stiction plug may provide a barrier to diffusion for the chamber and electrical interconnection for the contact area.

Notably, the trench may be formed simultaneously with the forming of the anti-stiction channel(s) through the encapsulation layer.

In second principal aspect, the present invention is a method of manufacturing an electromechanical device having a mechanical structure which is disposed over a substrate 5 and in a sealed chamber which is formed, at least in part, by an encapsulation structure. The method comprises forming at least one anti-stiction channel (for example, using anisotropic etching) through the substrate and introducing an anti-stiction fluid (for example, DDMS, OTS, PFOTCS, PFDA, FDTS, PFPE or FOTS) into the chamber via the at least one anti-stiction channel wherein the anti-stiction fluid forms a monolayer or self-assembled 10 layer on at least a portion of the mechanical structure. The method of this aspect of the invention also includes depositing an anti-stiction plug (for example, spin-on polymer, SOG or a metal material) over or in the anti-stiction channel to re-seal the chamber.

The method may also include securing the encapsulation structure over the mechanical structure using anodic bonding. The encapsulation structure includes an 15 anodic shield and an insulation layer, which is disposed on a cap wafer. The anodic shield may be disposed on the insulation layer.

The anti-stiction plug may be deposited using silk screening, shadow masking technology, or dispensed seal-glass, plastic and/or epoxy.

In one embodiment of this aspect of the invention, the electromechanical device may 20 include a contact area and the method further includes forming a trench around the contact area, wherein the contact area is at least partially disposed outside the chamber, and depositing a first insulating material in the trench to electrically isolate the contact area. The method may also include depositing a second insulating layer over at least a portion of

the trench and forming an anti-stiction window in the insulating layer before forming the at least one anti-stiction channel through the encapsulation layer. A highly conductive material may be deposited on the contact area and over the second insulating layer to provide electrical connection to the contact area wherein at least a portion of the anti-  
5 stiction plug is comprised of the highly conductive material.

In one embodiment, the method includes depositing a diffusion barrier on the anti-stiction plug. The diffusion barrier may be, for example, comprised of a polysilicon, germanium, silicon/germanium, silicon dioxide, silicon nitride, BPSG, PSG, SOG or metal bearing material. Indeed, a highly conductive material deposited on the contact area and  
10 over the insulating layer, and anti-stiction plug may provide a barrier to diffusion for the chamber and electrical interconnection for the contact area.

In a third principal aspect, the present invention is an electromechanical device comprising a substrate, a mechanical structure disposed over the substrate wherein a monolayer or self-assembled layer is disposed on at least a portion of the mechanical  
15 structure, and a film encapsulation structure, disposed over the mechanical structure, to define and seal a chamber. In addition, the electromechanical device includes an anti-stiction channel, etched into the film encapsulation structure, to provide access to at least a portion of the mechanical structure disposed in the chamber; and an anti-stiction plug (for example, spin-on polymer, SOG or a metal material), disposed over or in the anti-stiction  
20 channel, to re-seal the chamber.

In one embodiment, the film encapsulation structure may include first and second encapsulation layers. The first encapsulation layer may be comprised of polycrystalline silicon, porous polycrystalline silicon, amorphous silicon, silicon carbide, silicon nitride,

silicon/germanium, germanium, or gallium arsenide. The second encapsulation layer may be comprised of polycrystalline silicon, porous polycrystalline silicon, amorphous silicon, germanium, silicon/germanium, gallium arsenide, or silicon carbide.

In another embodiment, the electromechanical device may include a trap, disposed  
5 between the anti-stiction channel and the mechanical structure. The trap may be a substantially vertical trap or substantially horizontal trap.

The electromechanical device may also include a diffusion barrier disposed over the anti-stiction plug. The diffusion barrier may be comprised of a metal material.

In a fourth principal aspect, the present invention is an electromechanical device  
10 comprising a substrate, a mechanical structure disposed over the substrate wherein a monolayer or self-assembled layer is disposed on at least a portion of the mechanical structure, and a wafer bonded encapsulation structure, disposed over the mechanical structure, to define and seal a chamber. The electromechanical device of this aspect of the invention may also include an anti-stiction channel, etched into the substrate, to provide  
15 access to at least a portion of the mechanical structure disposed in the chamber and an anti-stiction plug (for example, spin-on polymer, SOG or a metal material), disposed over or in the anti-stiction channel, to re-seal the chamber.

The encapsulation structure may be secured over the mechanical structure using anodic bonding. As such, the encapsulation structure may include an anodic shield.  
20 Moreover, the encapsulation structure may include an insulation layer, which is disposed on a cap wafer, wherein the anodic shield is disposed on the insulation layer.

In one embodiment, the electromechanical device of this aspect may include a trap, disposed between the anti-stiction channel and the mechanical structure. The trap may be a substantially vertical trap or substantially horizontal trap.

The electromechanical device may also include a diffusion barrier disposed over the 5 anti-stiction plug. The diffusion barrier may be comprised of a metal material.

Again, there are many inventions described and illustrated herein. This Summary of the Invention is not exhaustive of the scope of the present invention. Moreover, this Summary is not intended to be limiting of the invention and should not be interpreted in that manner. While certain embodiments, features, attributes and advantages of the inventions 10 have been described in this Summary, it should be understood that many others, as well as different and/or similar embodiments, features, attributes and/or advantages of the present inventions, which are apparent from the description, illustrations and claims, which follow.

#### BRIEF DESCRIPTION OF THE DRAWINGS

In the course of the detailed description to follow, reference will be made to the 15 attached drawings. These drawings show different aspects of the present invention and, where appropriate, reference numerals illustrating like structures, components, materials and/or elements in different figures are labeled similarly. It is understood that various combinations of the structures, components, materials and/or elements, other than those specifically shown, are contemplated and are within the scope of the present invention.

20 FIGURE 1 illustrates a top view of a portion of micromechanical structure, for example, a portion of an interdigitated or comb-like finger electrode array, having

"moveable" electrodes and "fixed" electrodes, of an accelerometer, in conjunction with, among other things, a contact area;

FIGURE 2 illustrates a cross-sectional view (sectioned along dotted line a-a' of FIGURE 1) of the portion of the interdigitated or comb-like finger electrode array, contact 5 area of FIGURE 1 and a trench isolated contact, in conjunction with the anti-stiction plug or cap, in accordance with certain aspects of the present invention;

FIGURES 3A-3L illustrate cross-sectional views of the fabrication of MEMS, including the anti-stiction plug or cap, of FIGURE 2 at various stages of the process, according to certain aspects of the present invention;

10 FIGURE 4 illustrates a cross-sectional view of the anti-stiction layer deposited on the microstructure of FIGURE 2, according to certain aspects of the present invention;

FIGURE 5 illustrates a cross-sectional view (sectioned along dotted line a-a' of FIGURE 1) of the portion of the interdigitated or comb-like finger electrode array, contact area and a trench isolated contact, in conjunction with a trap and an anti-stiction plug or 15 cap, in accordance with certain aspects of the present invention;

FIGURE 6A-6L illustrate cross-sectional views of the fabrication of the anti-stiction plug or cap of FIGURE 5 at various stages of the process, according to certain aspects of the present invention;

FIGURES 7A and 7B illustrate the cross-sectional view of FIGURE 5, in conjunction 20 with the material of the anti-stiction plug "captured" by a trap, in accordance with certain aspects of the present invention;

FIGURES 8A and 8B illustrate cross-sectional views of the fabrication of a microstructure and an anti-stiction plug or cap including a diffusion barrier, according to certain aspects of the present invention;

FIGURE 9 illustrates a top view of a portion of another micromechanical structure, for example, a portion of an interdigitated or comb-like finger electrode array, having "moveable" electrodes and "fixed" electrodes, of an accelerometer, in conjunction with, among other things, a plurality of contact areas;

5 FIGURES 10A-10C and 11A-11C illustrate cross-sectional views (sectioned along dotted line a-a' of FIGURE 1) of the portion of the interdigitated or comb-like finger electrode array, contact area of FIGURE 1, in conjunction with the anti-stiction plug or cap, among other things, in accordance with certain aspects of the present invention;

10 FIGURE 12 is a block diagram of microelectromechanical system disposed on a substrate, in conjunction with interface circuitry and data processing electronics;

FIGURES 13A and 13B illustrate cross-sectional views of MEMS according to certain aspects of the present inventions, including a micromachined mechanical structure portion and an integrated circuit portion, both portions of which are disposed or integrated on or in a common substrate;

15 FIGURE 14 illustrates a cross-sectional view (sectioned along dotted line a-a' of FIGURE 1) of the portion of the interdigitated or comb-like finger electrode array and contact area of FIGURE 1, in conjunction with the anti-stiction plug or cap and wafer bonded encapsulation structure, in accordance with certain aspects of the present invention;

20 FIGURES 15A-15F illustrate cross-sectional views of the fabrication of the MEMS, including anti-stiction plug or cap, of FIGURE 14 at various stages of the process, according to certain aspects of the present invention;

FIGURES 16A-16F cross-sectional view (sectioned along dotted line a-a' of FIGURE 1) of the portion of the interdigitated or comb-like finger electrode array, contact

area and a trench isolated contact, in conjunction with an anti-stiction plug or cap, at various stages of the process, in accordance with another aspect of the present invention;

FIGURES 17A-17E cross-sectional views (sectioned along dotted line a-a' of FIGURE 1) of the portion of the interdigitated or comb-like finger electrode array, contact area and a trench isolated contact, in conjunction with an anti-stiction plug or cap, at various stages of the process, in accordance with another aspect of the present invention;

5 FIGURE 18 illustrates a cross-sectional view of the interdigitated or comb-like finger electrode array, contact area and a trench isolated contact, in conjunction with an anti-stiction plug or cap that is comprised of the same material as the conductive layer disposed above and in contact with the contact area, in accordance with another aspect of the present invention;

10 FIGURES 19A and 19B illustrate the cross-sectional view of FIGURE 18, in conjunction with a trap, in accordance with certain aspects of the present invention;

15 FIGURE 20A is a partial cross-sectional view (sectioned along dotted line a-a' of FIGURE 1) of the portion of the interdigitated or comb-like finger electrode array, in conjunction with a substantially horizontal trap, in accordance with certain aspects of the present invention;

20 FIGURE 20B is a (lateral) cross-sectional view (sectioned along dotted line A-A') of FIGURE 20A illustrating the serpentine shape of the substantially horizontal trap; and

FIGURES 21A and 21B illustrate cross-sectional views of a micromechanical structure, having a plurality of microstructures and a contact, which are monolithically integrated on or within the substrate of a MEMS, in accordance with certain aspect of the present invention.

## **DETAILED DESCRIPTION**

There are many inventions described and illustrated herein. In one aspect, the present invention is directed to a thin film or wafer encapsulated MEMS, and technique of fabricating or manufacturing a thin film or wafer encapsulated MEMS employing the anti-stiction techniques of the present invention. In one embodiment, after encapsulation of the MEMS, an anti-stiction channel is formed in the encapsulation layer(s) and/or the substrate thereby providing "access" to the chamber containing some or all of the active members or electrodes of the mechanical structures of the MEMS. Thereafter, an anti-stiction fluid (for example, gas or gas-vapor) is introduced into the chamber via the anti-stiction channel.

5 The anti-stiction fluid may deposit on one, some or all of the active members or electrodes of the mechanical structures thereby providing an anti-stiction layer (for example, a monolayer coating or self-assembled monolayer) and/or out-gassing molecules on such members or electrodes. In this way, the mechanical structures include suitable anti-stiction characteristics.

10 After introduction and/or application of the anti-stiction fluid, the anti-stiction channel may be sealed, capped, plugged and/or closed to define and control the mechanical damping environment within the chamber. In this regard, sealing, capping and/or closing the chamber establishes the environment within the chamber containing and/or housing the mechanical structures. This environment provides the predetermined, desired and/or selected mechanical damping of the mechanical structure as well as suitable hermeticity.

15 The parameters (for example, pressure) of the final encapsulated fluid (for example, a gas or a gas vapor) in which the mechanical structures are to operate may be controlled,

selected and/or designed to provide a desired and/or predetermined operating environment.

With reference to FIGURE 1, in one exemplary embodiment, MEMS 10 includes micromachined mechanical structure 12 that is disposed on substrate 14, for example, an 5 undoped semiconductor-like material, a glass-like material, or an insulator-like material. The micromachined mechanical structure 12 may be an accelerometer, gyroscope and/or other transducer (for example, pressure sensor, strain sensor, tactile sensor, magnetic sensor and/or temperature sensor), filter and/or resonator. The micromachined mechanical structure 12 may also include mechanical structures of a plurality of transducers or sensors 10 including, for example, one or more accelerometers, gyroscopes, pressure sensors, tactile sensors and temperature sensors.

With reference to FIGURE 2, in one embodiment, micromachined mechanical structure 12 includes mechanical structures 16a-d disposed on, above and/or in substrate 14. In particular, mechanical structures 16a, 16c and 16d may be "moveable" electrodes of 15 "moveable" mechanical members 18a and 18b. The mechanical structure 16b may be "fixed" electrodes of "fixed" mechanical member 20. Where micromachined mechanical structure 12 is an accelerometer, mechanical structures 16a-d may be a portion of the interdigitated or comb-like finger electrode arrays that comprise the sensing features of the accelerometer (see, for example, U.S. Patent 6,122,964).

20 The mechanical structures 16a-d may be comprised of, for example, materials in column IV of the periodic table, for example silicon, germanium, carbon; also combinations of these, for example, silicon germanium, or silicon carbide; also of III-V compounds for example, gallium phosphide, aluminum gallium phosphide, or other III-V combinations; also

combinations of III, IV, V, or VI materials, for example, silicon nitride, silicon oxide, aluminum carbide, or aluminum oxide; also metallic silicides, germanides, and carbides, for example, nickel silicide, cobalt silicide, tungsten carbide, or platinum germanium silicide; also doped variations including phosphorus, arsenic, antimony, boron, or aluminum doped

5 silicon or germanium, carbon, or combinations like silicon germanium; also these materials with various crystal structures, including single crystalline, polycrystalline, nanocrystalline, or amorphous; also with combinations of crystal structures, for instance with regions of single crystalline and polycrystalline structure (whether doped or undoped).

With continued reference to FIGURE 2, micromachined mechanical structure 12 may

10 also include a field area 22 and contact area 24 disposed on or in substrate 14. The field region 22 may provide a substrate material for the electronic or electrical components or integrated circuits (for example, transistors, resistors, capacitors, inductors and other passive or active elements). The contact area 24 may provide an electrical path between micromachined mechanical structure 12 and integrated or external electronics, integrated

15 interface circuitry, and/or an external device (not illustrated). The contact area 24 may be comprised of, for example, silicon, (whether doped or undoped), germanium, silicon/germanium, silicon carbide, and gallium arsenide, and combinations and/or permutations thereof.

The micromachined mechanical structure 12 further includes chamber 26 having an

20 atmosphere 28 "contained" therein. The chamber 26 is formed, at least in part, by encapsulation layer(s) 30. In this regard, MEMS 10 may be sealed in chamber 26 using conventional thin film encapsulation techniques and structures. (See, for example, WO 01/77008 A1 and WO 01/77009 A1). Other thin film encapsulation techniques are suitable.

Indeed, all thin film encapsulation techniques, whether now known or later developed, are intended to be within the scope of the present invention.

For example, the encapsulation techniques described and illustrated in non-provisional patent application entitled "Microelectromechanical Systems Having Trench Isolated Contacts, and Methods of Fabricating Same", which was filed on June 4, 2003 and assigned Serial No. 10/455,555 (hereinafter "Microelectromechanical Systems Having Trench Isolated Contacts Patent Application"), may be employed in conjunction with the anti-stiction techniques of the present invention. For the sake of brevity, the inventions described and illustrated in the Microelectromechanical Systems Having Trench Isolated Contacts Patent Application, implemented in conjunction with the inventions described and illustrated herein, will not be repeated but will only be summarized. It is expressly noted, however, that the entire contents of the Microelectromechanical Systems Having Trench Isolated Contacts Patent Application, including, for example, the features, attributes, alternatives, materials, techniques and advantages of all of the inventions, are incorporated by reference herein.

The micromachined mechanical structure 12 of the present invention also includes anti-stiction channel 32 formed through, for example, encapsulation layer(s) 30 to facilitate fluid communications with and/or provide an access or a pathway to mechanical structures 16a-d in chamber 26 after completion of the encapsulation process (i.e., deposition, formation and/or growth of encapsulation layer(s) 30). In this regard, after encapsulation of mechanical structures 16a-d and formation of chamber 26, anti-stiction channel 32 may be formed using, for example, anisotropic etching techniques (for example, deep reactive ion etching). In one embodiment, "diameter" or "width" of anti-stiction channel 32 may be

between 100nm to 50 $\mu$ m and preferably between 200nm and 10 $\mu$ m. Notably, the "diameter" or "width" of anti-stiction channel 32 may depend on the thickness of the encapsulation layer(s) 30.

Thereafter, an anti-stiction fluid (for example, dichlorodimethylsilan ("DDMS"), 5 octadecyltrichlorsilan ("OTS"), perfluorooctyltrichlorsilan ("PFOTCS"), perfluorodecanoic acid ("PFDA"), perfluorodecyl-trichlorosilane ("FDTs"), perfluoro polyether ("PFPE") and/or fluoroalkylsilane ("FOTS")) may be introduced into chamber 26 by, for example, vapor deposition (for example, APCVD, LPCVD, or PECVD). The anti-stiction fluid may deposit 10 on one, some or all of mechanical structures 16a-d of MEMS 12 thereby providing an anti-stiction layer, for example, a monolayer coating and/or out-gassing molecules on the mechanical structures. In this way, mechanical structures 16a-d include suitable anti-adhesive properties.

The parameters of introducing the anti-stiction fluid may impact, for example, the characteristics of the anti-stiction layer (for example, the monolayer or self-assembled 15 monolayer) on mechanical structures 16a-d. For example, introducing the anti-stiction fluid at higher temperatures may tend to enhance the diffusivity of the fluid whereas introducing the anti-stiction fluid at lower temperatures may tend to enhance the anti-stiction properties of the fluid. Thus, in one embodiment, the anti-stiction fluid is introduced between 20°C to 600°C, and preferably between 100°C and 300°C.

20 Moreover, introducing the anti-stiction fluid at higher pressures may tend to enhance the deposition rate of the anti-stiction layer (for example, the monolayer or self-assembled monolayer) on mechanical structures 16a-d. In contrast, lower pressures may increase the number of molecules that enter further down into chamber 26 due to the larger mean free

path of the molecules via anti-stiction channel 32. Thus, in one embodiment, the anti-stiction fluid is introduced between 100  $\mu$ Torr and 1 Torr.

It may be advantageous to employ deposition parameters of the anti-stiction layer that provides or forms the anti-stiction layer more conformally. In this way, anti-stiction  
5 channel 32 is less likely to close, as a result of "build-up" of the anti-stiction material within or above anti-stiction channel 32, before a sufficient anti-stiction layer forms on mechanical structures 16a-d. Notably, the anti-stiction fluid may be any material that enhances the non-reactive and/or non-adhesive nature of, for example, the surface of mechanical structures 16a-d.

10 The anti-stiction channel 32 may be "closed" and/or "sealed" via channel plug 34. In this regard, channel plug 34 may be any material that seals, plugs and/or closes anti-stiction channel 32. For example, channel plug 34 may be a spin-on polymer, spin-on glass ("SOG"), metal material (for example, metal that is sputtered and, if necessary patterned). Further, channel plug 34 may be formed using/from silk screening of or  
15 dispensed seal-glass, plastic and/or epoxy. In addition, a shadow mask technology may be employed to seal, plug and/or close anti-stiction channel 32. Indeed, any material (and corresponding fabrication technique) may be implemented that, in one embodiment, provides a barrier to maintain a suitable environment in chamber 26 and is formed, applied and/or grown using parameters (for example, a temperature) that will not (1) destroy and/or  
20 obliterate the anti-stiction affects provided by the anti-stiction fluid (for example, destruction of the monolayer coating on the mechanical structures) and/or (2) prevent the anti-stiction technique of the present invention from providing suitable anti-stiction characteristics. In

this way, after sealing and/or closing anti-stiction channel 32, mechanical structures 16a-d retain suitable anti-stiction characteristics and/or properties.

As mentioned above, an exemplary method of fabricating or manufacturing a thin film encapsulated MEMS 10 is described and illustrated in the Microelectromechanical Systems Having Trench Isolated Contacts Patent Application. For the sake of brevity, those discussions and illustrations will not be repeated but will only be summarized. It is expressly noted, however, that the entire contents of the Microelectromechanical Systems Having Trench Isolated Contacts Patent Application, including, for example, the features, attributes, alternatives, materials, techniques and advantages of all of the inventions, are incorporated by reference herein.

With reference to FIGURE 3A, MEMS 10 may begin with an SOI substrate partially formed device including mechanical structures 16a-d and contact area 24 disposed on first sacrificial layer 36, for example, silicon dioxide or silicon nitride. The mechanical structures 16a-d and contact area 24 may be formed using well-known deposition, lithographic, etching and/or doping techniques as well as from well-known materials (for example, semiconductors such as silicon, germanium, silicon-germanium or gallium-arsenide). Moreover, field region 22 and first sacrificial layer 36 may be formed using well-known silicon-on-insulator fabrication techniques (FIGURE 3A) or well-known formation, lithographic, etching and/or deposition techniques using a standard or over-sized ("thick") wafer (not illustrated).

With reference to FIGURE 3B, following formation of mechanical structures 16a-d and contact area 24, second sacrificial layer 38, for example, silicon dioxide or silicon nitride, may be deposited and/or formed to secure, space and/or protect mechanical

structures 16a-d during subsequent processing, including the encapsulation process. In addition, an opening 40 may be etched and/or formed in second sacrificial layer 38 to provide for subsequent formation of an electrical contact. The opening 40 may be provided using, for example, well known masking techniques (such as a nitride mask) prior to and 5 during deposition and/or formation of second sacrificial layer 38, and/or well known lithographic and etching techniques after deposition and/or formation of second sacrificial layer 38.

With reference to FIGURES 3C, 3D and 3E, thereafter, first encapsulation layer 30a may be deposited, formed and/or grown on second sacrificial layer 38 (see, FIGURE 3C). 10 In one embodiment, the thickness of first encapsulation layer 30a in the region overlying second sacrificial layer 38 may be between 0.1 $\mu$ m and 5.0 $\mu$ m. The external environmental stress on, and internal stress of first encapsulation layer 30a after etching second sacrificial layer 38 may impact the thickness of first encapsulation layer 30a. Slightly tensile films may self-support better than compressive films which may buckle.

15 The first encapsulation layer 30a may be etched to form passages or vents 42 (see, FIGURE 3D). In one exemplary embodiment, vents 42 have a diameter or aperture size of between 0.1 $\mu$ m to 2 $\mu$ m. The vents 42 permit etching and/or removal of at least selected portions of first and second sacrificial layers 36 and 38, respectively (see, FIGURE 3E).

As mentioned in the Microelectromechanical Systems Having Trench Isolated 20 Contacts Patent Application, contact 24 may remain partially, substantially or entirely surrounded by portions of first and second sacrificial layers 36 and/or 38. For example, with reference to FIGURE 3E, while mechanical structures 20a-d are released from their

respective underlying oxide columns, a portion 44 of sacrificial layer 38 (i.e., juxtaposed electrical contact area 24 may remain after etching or removing second sacrificial layer 38.

With reference to FIGURE 3F, after releasing mechanical elements 16a-d, second encapsulation layer 30b may be deposited, formed and/or grown. The second encapsulation layer 30b may be, for example, a silicon-based material (for example, a polycrystalline silicon or silicon-germanium), which is deposited using, for example, an epitaxial, a sputtering or a CVD-based reactor (for example, APCVD, LPCVD, or PECVD). The deposition, formation and/or growth may be by a conformal process or non-conformal process. The material may be the same as or different from first encapsulation layer 30a.

10        Thereafter, contact area 24 of micromachined mechanical structure 12 is dielectrically isolated from the surrounding conductor and/or semiconductor layers. With reference to FIGURES 3G and 3H, trenches 46a and 46b may be etched. The trenches 46a and 46b may include a slight taper in order to facilitate the formation of dielectric isolation regions 48a and 48b. In this regard, an insulating material may be deposited in  
15      trenches 46a and 46b to form dielectric isolation regions 48a and 48b, respectively. The insulating material may be, for example, silicon dioxide, silicon nitride, BPSG, PSG, or SOG.

The insulating layer 50 may be deposited, formed and/or grown on the exposed surface of second encapsulating layer 30b to provide insulation between the various  
20      surrounding conductive and/or semiconductor layers and the subsequent conductive layer.

Thus, during deposition, formation and/or growth of insulation layer 50, trenches may also be filled to form dielectric isolation regions 48a and 48b. (see, FIGURE 3H). Thereafter, contact opening 52 may be etched to facilitate electrical connection to contact area 24. A

conductive layer 54 may then be deposited and/or formed to provide the appropriate electrical connection to contact 24. (see, FIGURE 3I).

Thereafter, with reference to FIGURE 3K, anti-stiction channel window 56 may be formed and/or etched in insulation layer 50, using conventional etching techniques, in order 5 to define the location of anti-stiction channel 32. The anti-stiction channel 32 is formed through encapsulation layer(s) 30 to provide access to mechanical structures 16a-d. (see, FIGURE 3K). The anti-stiction channel 32 may be formed using, for example, well-known anisotropic etching techniques (for example, deep reactive ion etching).

After formation of anti-stiction channel 32, an anti-stiction fluid may be introduced 10 into chamber 26. The anti-stiction fluid may be, for example, DDMS, OTS, PFOTCS, PFDA, FDTD, PFPE and/or FOTS. Indeed, any anti-stiction fluid may be employed provided that the subsequent processes do not destroy the anti-stiction characteristics and/or destroy or obliterate the anti-stiction deposition on mechanical structures 16a-d of MEMS 12. In this way, the anti-stiction layer 58, for example, the monolayer coating 15 formed on mechanical structures 16a-d, remains relatively intact and mechanical structures 16a-d include suitable anti-adhesive properties to overcome the adhesive forces of adjacent structures or elements in MEMS 10.

With reference to FIGURE 3L, anti-stiction channel 32 may be closed via channel plug 34. In this regard, channel plug 34 may be any material that seals, plugs and/or 20 closes anti-stiction channel 32. For example, channel plug 34 may be a spin-on polymer, spin-on glass ("SOG"), metal material that is sputtered and, if necessary patterned. Further, channel plug 34 may be formed using/from silk screening of seal-glass, plastic and/or epoxy. In addition, a shadow mask technology may be employed to seal, plug

and/or close anti-stiction channel 32. Indeed, any material (and corresponding fabrication technique) may be employed to form channel plug 34 provided the process of forming channel plug 34 uses parameters (for example, a temperature) that will not (1) destroy and/or obliterate the anti-stiction affects provided by the anti-stiction fluid (for example, 5 destruction of the monolayer coating on the mechanical structures) and/or (2) prevent the anti-stiction technique of the present invention from providing suitable anti-stiction or anti-adhesive characteristics.

Notably, the anti-stiction fluid may be a gas or gas vapor of a material used during the formation of channel plug 34. Indeed, the anti-stiction fluid may be a by-product of the 10 reaction of the material of MEMS 10 and the gas or gas vapor of a material used during the formation of channel plug 34. For example, a mixture of solvents and/or a polymer which outgases appropriate molecules such as DDMS.

The state of the fluid within chamber 26 (for example, the pressure), after deposition and/or formation of channel plug 34 may be determined using conventional techniques 15 and/or using those techniques described and illustrated in non-provisional patent application entitled "Electromechanical System having a Controlled Atmosphere, and Method of Fabricating Same", which was filed on March 20, 2003 and assigned Serial No. 10/392,528 (hereinafter "the Electromechanical System having a Controlled Atmosphere Patent Application"). For the sake of brevity, all of the inventions regarding controlling the 20 atmosphere within chamber 26 which are described and illustrated in the Electromechanical System having a Controlled Atmosphere Patent Application will not be repeated here. It is expressly noted, however, that the entire contents of the Electromechanical System having a Controlled Atmosphere Patent Application, including,

for example, the features, attributes, alternatives, materials, techniques and advantages of all of the inventions, are incorporated by reference herein.

With reference to FIGURE 4, in certain embodiments, anti-stiction layer 58, for example, a thin and/or monolayer coating is formed on mechanical structures 16a-d as a 5 result of the introduction of the anti-stiction fluid and/or formation of channel plug 34. The thin and/or monolayer coating provides suitable anti-adhesive properties that overcome the adhesive forces of adjacent structures or elements in MEMS 10. Notably, anti-stiction layer 58, for example, the thin and/or monolayer coating does not detrimentally impact the operation of mechanical structures 12 of MEMS 10.

10 In another embodiment of the present invention, a vertical and/or horizontal trap is formed in the vicinity of anti-stiction channel 32. The trap 60 may be positioned between anti-stiction channel 32 and mechanical structures 16a-d. In this way, where certain materials (i.e., the material(s) used to form channel plug 34) are employed to seal, plug and/or close anti-stiction channel 32 that may escape from anti-stiction channel 32, trap 60 15 "captures" or "catches" that material before it enters that portion of chamber 26 where mechanical structures 16a-d reside. Under this circumstance, the channel plug material that enters chamber 26 is routed away from mechanical structures 16a-d and, as such, is "prevented" from contacting and/or impacting mechanical structures 16a-d and the operation thereof. For example, with reference to FIGURE 5, trap 60 may be a 20 substantially vertical trap, which is located between anti-stiction channel 32 and mechanical structures 16a-d.

With reference to FIGURE 6A, an exemplary embodiment of MEMS 10 having trap 60 may begin with an SOI substrate partially formed device including mechanical structures

16a-d, contact area 24, and trap 60 disposed on first sacrificial layer 36, for example, silicon dioxide or silicon nitride. The mechanical structures 16a-d, contact area 24 and trap 60 may be formed using well-known deposition, lithographic, etching and/or doping techniques as well as from well-known materials (for example, semiconductors such as 5 silicon, germanium, silicon-germanium or gallium-arsenide).

Thereafter, the processing of MEMS 10 having trap 60 may proceed in the same manner as described above with respect to FIGURES 3B-3L. In this regard, an exemplary fabrication process of MEM 10 including trap 60 is illustrated in FIGURES 6B-6L. Because the processes are substantially similar to the discussion above with respect to FIGURES 10 3B-3L, for the sake of brevity, that discussion will not be repeated.

As mentioned above, trap 60 of FIGURE 5 is designed to prevent the material(s) that are deposited to seal, plug and/or close anti-stiction channel 32 from adversely impacting the operation of mechanical structures 16a-d. With reference to FIGURES 7A and 7B, in one embodiment, trap 60 is positioned and/or located to route material 62 that may leak 15 and/or escape from anti-stiction channel 32 during deposition and/or formation of channel plug 34 away from mechanical structures 16a-d. In this regard, trap 60 "captures" material 62 before it enters that portion of chamber 26 where mechanical structures 16a-d reside. Under this circumstance, material 62 that enters chamber 26 is "prevented" from contacting and/or adversely impacting mechanical structures 16a-d and the operation thereof.

With reference to FIGURES 8A and 8B, in another embodiment, after fabrication of 20 channel plug 34, diffusion barrier 64 may be deposited and/or formed over anti-stiction channel 32 and/or channel plug 34 in order to enhance the "seal" of anti-stiction channel 32 and thereby enhance the barrier to diffusion of fluid within (or external to) chamber 26 (for

example, enhance the hermeticity of MEMS 10). Thus, diffusion barrier 64 alone, or in combination with channel plug 34, "traps" the fluid (having a selected, desired and/or predetermined state) in chamber 26.

The diffusion barrier 64 may be, for example, a semiconductor material (for example, 5 a polysilicon, germanium, or silicon/germanium), an insulator material (for example, silicon dioxide, silicon nitride, BPSG, PSG, or SOG) or metal bearing material (for example, silicides). The diffusion barrier 64 may be, for example deposited, formed or grown using, for example, an epitaxial, a sputtering or a CVD-based reactor (for example, APCVD, LPCVD or PECVD). The deposition, formation and/or growth may be by a conformal 10 process or non-conformal process. The material comprising diffusion barrier 64 may be the same as or different from channel plug 34. However, it may be advantageous to employ a low temperature deposition process (and a material that is amenable to such a deposition technique) in order to preserve and/or protect the anti-stiction barrier, layer and/or affects provided by the anti-stiction fabrication processes of the present invention.

15 The diffusion barrier 64 may be formed and/or deposited before formation and/or deposition of conductive layer 54, during formation and/or deposition of conductive layer 54 (see, for example, FIGURE 8A), or after formation and/or deposition of conductive layer 54 (see, for example, FIGURE 8B).

Notably, diffusion barrier 64 may be implemented in any of the embodiments 20 described herein, for example, the embodiments illustrated in FIGURES 3A-3L. For the sake of brevity, that discussion will not be repeated or restated.

As mentioned above, the present inventions may be implemented in conjunction with various thin film encapsulation techniques, including the encapsulation techniques

described and illustrated in non-provisional patent application entitled "Microelectromechanical Systems, and Method of Encapsulating and Fabricating Same", which was filed on June 4, 2003 and assigned Serial No. 10/454,867 (hereinafter "Microelectromechanical Systems and Method of Encapsulating Patent Application"). In 5 this regard, any and all of the embodiments described herein may be incorporated into the MEMS 10 of Microelectromechanical Systems and Method of Encapsulating Patent Application (see, for example FIGURES 9, 10A-10C, and 11A-11C). For the sake of brevity, the inventions described and illustrated in the Microelectromechanical Systems and 10 Method of Encapsulating Patent Application, implemented in conjunction with the anti-stiction inventions described and illustrated herein, will not be repeated. It is expressly noted, however, that the entire contents of the Microelectromechanical Systems and Method of Encapsulating Patent Application, including, for example, the features, attributes, alternatives, materials, techniques and advantages of all of the embodiments and/or inventions, are incorporated by reference herein.

15 It should be noted that the present invention may be implemented in a MEMS including micromachined mechanical structure as well as data processing electronics and/or interface circuitry. With reference to FIGURE 12, in one exemplary embodiment, MEMS 10 includes micromachined mechanical structure 12 that is disposed on substrate 14, for example, an undoped semiconductor-like material, a glass-like material, or an 20 insulator-like material. The MEMS 10 may also include data processing electronics 16 to process and analyze information generated by, and/or control or monitor the operation of micromachined mechanical structure 12. In addition, MEMS 10 may also include interface circuitry 18 to provide information from micromachined mechanical structure 12 and/or data

processing electronics 16 to an external device (not illustrated), for example, a computer, indicator/display and/or sensor.

The data processing electronics 70 and/or interface circuitry 72 may be integrated in or on substrate 14. In this regard, MEMS 10 may be a monolithic structure including 5 mechanical structure 12, data processing electronics 70 and interface circuitry 72. The data processing electronics 70 and/or interface circuitry 72 may also reside on a separate, discrete substrate that, after fabrication, is bonded to or on substrate 14.

For example, with reference to FIGURES 13A and 13B, integrated circuits 74 may be fabricated using conventional techniques after definition of mechanical structure 12 10 using, for example, the techniques described and illustrated in Microelectromechanical Systems and Method of Encapsulating Patent Application and/or Microelectromechanical Systems Having Trench Isolated Contacts Patent Application (see, for example, FIGURE 13B). In this regard, after fabrication and encapsulation of mechanical structure 12, integrated circuits 74 may be fabricated using conventional techniques and interconnected 15 to contact area 24 by way of conductive layer 54. In particular, as illustrated and described in Microelectromechanical Systems and Method of Encapsulating Patent Application (for example, FIGURES 12A-C thereof) and/or Microelectromechanical Systems Having Trench Isolated Contacts Patent Application (for example, FIGURES 14A-E thereof), the contact area is accessed directly by integrated circuitry 74 via a low resistance electrical path (i.e., 20 conductive layer 54) that facilitates a good electrical connection. The insulation layer 50 may be deposited, formed and/or grown and patterned and, thereafter, conductive layer 54 (for example, a heavily doped polysilicon or metal such as aluminum, chromium, gold, silver, molybdenum, platinum, palladium, tungsten, titanium, and/or copper) is formed.

With continued reference to FIGURES 13A and 13B, thereafter, the anti-stiction techniques of the present invention(s) may be implemented. That is, anti-stiction channel window 56 may be etched and/or formed in insulation layer 50 and anti-stiction channel 32 may be etched and/or formed in encapsulation layer(s) 30. The anti-stiction fluid may be

5 introduced into chamber 26 via anti-stiction channel 32 thereby forming, for example, an anti-stiction layer 58 on mechanical structures 16. Thereafter or concurrently therewith, anti-stiction channel 32 may be closed and/or sealed by channel plug 34 and/or diffusion barrier 64.

Notably, while the anti-stiction processes were described as being implemented after deposition and/or formation of insulation layer 50 and conductive layer 54, the anti-stiction processes of the MEMS 10 illustrated in FIGURES 13A and 13B may be performed in another order. That is, contact opening 52 and anti-stiction channel window 56 may be fabricated either consecutively or simultaneously. Moreover, the anti-stiction fabrication/processes may be performed after deposition of conductive layer 54 or before

10 fabrication of deposition of conductive layer 54. In addition, channel plug 34 may be formed and/or deposited simultaneously with the formation and/or deposition of conductive layer 54.

In another aspect, the present invention employs wafer-bonding encapsulation techniques, in conjunction with the anti-stiction techniques described above. In this regard,

15 with reference to FIGURE 14, in one embodiment, MEMS 10 includes micromachined mechanical structure 12 and wafer bonded encapsulation structure 76. The micromachined mechanical structure 12 may be fabricated using any of the techniques described and illustrated herein or using conventional techniques.

The wafer bonded encapsulation structure 76 may be bonded and/or "attached", using, for example, anodic bonding. In one embodiment, wafer bonded encapsulation structure 76 includes cap wafer 78 (for example, silicon), insulation layer 80 (for example, SOG or Pyrex) and anodic shield 82 (for example, a metal). Notably, wafer bonded 5 encapsulation structure 76 may be bonded and/or "attached" using conventional techniques.

In one embodiment, the anti-stiction techniques described and illustrated above are "applied" to the exposed surface of substrate 14. In this regard, anti-stiction channel 32 is formed in substrate 14 and, thereafter an anti-stiction fluid is introduced into chamber 26, 10 as described above. The anti-stiction plug 34 is then deposited and/or formed "re-seal" chamber 26.

For example, with reference to FIGURES 15A, MEMS 10 may begin with an SOI substrate partially formed device including "released" mechanical structures 16a-d and contact area 24 partially disposed on first sacrificial layer 36, for example, silicon dioxide or 15 silicon nitride. The fabrication and/or formation of the structures of micromachined mechanical structure 12 may be accomplished using the techniques described and illustrated herein or any conventional technique. Indeed, all techniques and materials used to fabricate and/or form mechanical structure 12, whether now known or later developed, are intended to be within the scope of the present invention.

20 With reference to FIGURE 15B, thereafter, wafer bonded encapsulation structure 76 may be "applied" and/or bonded to micromachined mechanical structure 12. For example, in one embodiment, wafer bonded encapsulation structure 76 is bonded using anodic techniques. Notably, wafer bonded encapsulation structure 76 may be "bonded" to

micromachined mechanical structure 12 using conventional techniques. In addition, all techniques and materials used to fabricate and/or form wafer bonded encapsulation structure 76, whether now known or later developed, are intended to be within the scope of the present invention.

5 With reference to FIGURES 15C and 15D, substrate 14 may be thinned (for example, to a thickness of between 20 $\mu$ m to 200 $\mu$ m, to facilitate contact or interconnection to contact area 24. In this regard, contact area 24 may be isolated via trenches 46a and 46b using an anisotropic etching technique (see, FIGURE 15C) as described in detail above. Thereafter, an electrical path may be deposited and/or formed to interconnect  
10 contact area 24 with, for example, integrated or external electronics and/or circuitry. In this regard, conductive layer 54 may be deposited and/or formed after deposition of insulation layer 50. (See, FIGURE 15D)

With reference to FIGURES 15E and 15F, anti-stiction channel 32 may be formed (see, FIGURE 15E), and an anti-stiction fluid may be introduced into chamber 26. The  
15 techniques described and illustrated above may be applied here. After (or concurrently with) introduction of the anti-stiction fluid, channel plug 34 may be deposited and/or formed to "seal" anti-stiction channel 32. As mentioned above, channel plug 34 may be a spin-on polymer, SOG, metal material. Moreover, channel plug 34 may be formed using/from silk screening of or dispensed seal-glass, plastic and/or epoxy. Indeed, any material (and  
20 corresponding fabrication technique) may be implemented that, in one embodiment, provides a barrier to maintain a suitable environment in chamber 26 and is formed, applied and/or grown using parameters (for example, a temperature) that will not (1) destroy and/or obliterate the anti-stiction affects provided by the anti-stiction fluid (for example, destruction

of the monolayer coating on the mechanical structures) and/or (2) prevent the anti-stiction technique of the present invention from providing suitable anti-stiction characteristics.

Notably, as described above, a diffusion barrier may be incorporated to enhance the "seal" of chamber 26. The diffusion barrier alone, or in combination with channel plug 34, 5 "traps" the fluid (having a selected, desired and/or predetermined state) in chamber 26. Thus, after sealing and/or closing anti-stiction channel 32, mechanical structures 16a-d retain suitable anti-stiction characteristics and/or properties.

It should be further noted that all of the anti-stiction techniques described and illustrated in connection with the thin film wafer fabrication (for example, FIGURES 2, 5, 8A 10 and 8B) may be applied to the wafer bonded encapsulation embodiment. For the sake of brevity, those discussions will not be repeated.

There are many inventions described and illustrated herein. While certain embodiments, features, materials, configurations, attributes and advantages of the inventions have been described and illustrated, it should be understood that many other, as 15 well as different and/or similar embodiments, features, materials, configurations, attributes, structures and advantages of the present inventions that are apparent from the description, illustration and claims. As such, the embodiments, features, materials, configurations, attributes, structures and advantages of the inventions described and illustrated herein are not exhaustive and it should be understood that such other, similar, as well as different, 20 embodiments, features, materials, configurations, attributes, structures and advantages of the present inventions are within the scope of the present invention.

For example, while the exemplary embodiments and/or processes of the invention have been described above according to a particular order, that order should not be

interpreted as limiting. For example, contact opening 52 and anti-stiction channel window 56 may be fabricated either consecutively (see, for example, FIGURE 3I-3K and FIGURES 16B-16E) or simultaneously (see, for example, FIGURE 20B). Moreover, the anti-stiction fabrication/processes may be performed after deposition of conductive layer 54 (see, for 5 example, FIGURES 3J-3L) or before fabrication of deposition of conductive layer 54 (see, for example, FIGURES 17A-17F).

Indeed, anti-stiction channel 32 may be comprised of a plurality of channels etched in substrate 14, encapsulation layer(s) 30 and/or wafer bonded encapsulation structure 76.

The channels may be located at selected sites to more efficiently, fully and/or evenly 10 provide the anti-stiction fluid within chamber and thereby more efficiently, fully and/or evenly/conformally provide an anti-stiction layer (for example, a monolayer coating or self-assembled monolayer) on micromachined mechanical structure 12. In this regard, the anti-stiction channels 32 may be, for example, evenly situated or placed around substrate 14, encapsulation layer(s) 30 and/or wafer bonded encapsulation structure 76, or distributed 15 according to the relative concentration of structures 16 (for example, more channels 32 concentrated in regions or areas of dense mechanical structures and/or less channels 32 concentrated in regions or areas of less "populated" by mechanical structures).

In addition, it may be advantageous to locate the anti-stiction channels 32 in accordance with regions or areas where the mechanical structures are more likely to 20 contact other structures or elements of micromachined mechanical structure 12 and/or are more susceptible to the debilitating effects of stiction. In this way, the anti-stiction fluid is more likely to efficiently, fully and/or evenly/conformally provide an anti-stiction layer (for

example, a monolayer coating or self-assembled monolayer) on such mechanical structures of micromachined mechanical structure 12.

Further, channel plug 34 may be formed and/or deposited simultaneously with the formation and/or deposition of conductive layer 54. In this embodiment, channel plug 34

5 may be a metal or highly doped semiconductor material (for example, highly doped polysilicon). (See, for example, FIGURE 18). In those instances where channel plug 34 is comprised of a metal, it may be advantageous to employ trap 60 to "protect" micromachined mechanical structure 12 in the event that the metal material enters chamber 26 (see, for example, FIGURES 19A and 19B).

10 Moreover, trap 60 may take any vertical and/or horizontal shape in one or more of the layers of micromachined mechanical structure 12. For example, trap 60 may be formed within encapsulation layer(s) 30 as a substantially horizontal trap that includes serpentine shape before access to chamber 26 (see, for example, FIGURES 20A and 20B).

In addition, as mentioned above, the anti-stiction techniques described herein may

15 be implemented in conjunction with micromachined mechanical structures 12 having one or more transducers or sensors which may themselves include multiple layers that are vertically and/or laterally stacked or interconnected as illustrated in Microelectromechanical Systems and Method of Encapsulating Patent Application and/or Microelectromechanical Systems Having Trench Isolated Contacts Patent Application. Accordingly, any and all of

20 the anti-stiction inventions and/or embodiments illustrated and described herein may be implemented in the embodiments of Microelectromechanical Systems and Method of Encapsulating Patent Application and/or Microelectromechanical Systems Having Trench Isolated Contacts Patent Application that include multiple layers of mechanical structures,

contacts areas and buried contacts that are vertically and/or laterally stacked or interconnected (see, for example, micromachined mechanical structure 12 of FIGURES 11B, 11C and 11D of Microelectromechanical Systems and Method of Encapsulating Patent Application and/or micromachined mechanical structure 12 of FIGURES 13B, 13C 5 and 13D of Microelectromechanical Systems Having Trench Isolated Contacts Patent Application). Under this circumstance, the MEMS may be fabricated using the anti-stiction techniques described in this application wherein the mechanical structures include one or more processing steps to provide the vertically and/or laterally stacked and/or interconnected multiple layers (see, for example, FIGURES 21A and 21B).

10           Thus, any of the techniques, materials and/or embodiments of fabricating and/or encapsulating micromachined mechanical structure 12 that are described in the Microelectromechanical Systems and Method of Encapsulating Patent Application and/or in the Microelectromechanical Systems Having Trench Isolated Contacts Patent Application may be employed with the embodiments and/or the inventions described herein.

15           Moreover, the present invention may implement the anchors and techniques of anchoring mechanical structures 16 to substrate 14 (as well as other elements of MEMS 10, for example, contact 24) described and illustrated in "Anchors for Microelectromechanical Systems Having an SOI Substrate, and Method for Fabricating Same", which was filed on July 25, 2003 and assigned Serial No. 10/627,237 (hereinafter 20 the "Anchors for Microelectromechanical Systems Patent Application"). In this regard, with reference to FIGURES 19A and 19B, in one embodiment, anchors 66 and/or 68 may be comprised of a material that is relatively unaffected by the release processes of the mechanical structures. In this regard, the etch release process are selective or preferential

to the material(s) securing mechanical structures 16 in relation to the material comprising anchors 66. Moreover, anchors 66 and/or 68 may be secured to substrate 14 in such a manner that removal of insulation layer 50 has little to no affect on the anchoring of mechanical structures 16 to substrate 14.

5        It should be noted that the embodiments described herein may be incorporated into MEMS 10 described and illustrated in Anchors for Microelectromechanical Systems Patent Application. For the sake of brevity, the inventions and/or embodiments described and illustrated in the Anchors for Microelectromechanical Systems Patent Application, implemented in conjunction with the anti-stiction inventions described and illustrated herein, 10 will not be repeated. It is expressly noted, however, that the entire contents of the Anchors for Microelectromechanical Systems Patent Application, including, for example, the features, attributes, alternatives, materials, techniques and advantages of all of the embodiments and/or inventions, are incorporated by reference herein.

The term "depositing" and other forms (i.e., deposit, deposition and deposited) in the 15 claims, means, among other things, depositing, creating, forming and/or growing a layer of material using, for example, a reactor (for example, an epitaxial, a sputtering or a CVD-based reactor (for example, APCVD, LPCVD, or PECVD)).

Further, in the claims, the term "contact" means a conductive region, partially or wholly disposed outside the chamber, for example, the contact area and/or contact via.

20        It should be further noted that while the present inventions have been described in the context of microelectromechanical systems including micromechanical structures or elements, the present inventions are not limited in this regard. Rather, the inventions described herein are applicable to other electromechanical systems including, for example,

nanoelectromechanical systems. Thus, the present inventions are pertinent to electromechanical systems, for example, gyroscopes, resonators, temperatures sensors and/or accelerometers, made in accordance with fabrication techniques, such as lithographic and other precision fabrication techniques, which reduce mechanical components to a scale that is generally comparable to microelectronics. Indeed, any MEMS structure that is encapsulated by using thin film packaging or wafer bonding techniques, and subsequently "opened", and, after application or introduction of an anti-stiction fluid, is "re-sealed" is to be within the scope of the present invention.

Finally, as mentioned above, all of the embodiments of the present invention described and illustrated herein may be implemented in the embodiments of Microelectromechanical Systems and Method of Encapsulating Patent Application and/or Microelectromechanical Systems Having Trench Isolated Contacts Patent Application and/or Anchors for Microelectromechanical Systems Patent Application. For the sake of brevity, those permutations and combinations will not be repeated but are incorporated by reference herein.